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Abstract: The Meadowbank gold deposits are located in the Archean Woodburn Lake group of the western Churchill Province. The stratigraphy that hosts the deposits consists of felsic to intermediate volcaniclastic rocks and interbedded iron-formation. The stratigraphic sequence is polydeformed, with four phases of deformation recognized regionally; two of which have substantially modified the geometry of the strata. The initial phase of deformation was a progressive transposition of the stratigraphy with tight to isoclinal folding that culminated in low-angle, high-strain zones. This progressive deformation event appears to have controlled the distribution of gold mineralization. Overprinting, northeast-southwest, shallow-plunging folds further modified the geometry of the mineralized body.

Résumé : Les gisements aurifères de Meadowbank se trouvent dans le groupe archéen de Woodburn Lake dans la partie occidentale de la Province de Churchill. Les strates géologiques encaissantes sont constituées de roches volcanoclastiques de composition felsique à intermédiaire et d'une formation de fer interstratifiée. La séquence stratigraphique est polydéformée, quatre phases de déformation étant reconnues à l'échelle régionale. Deux d'entre elles ont considérablement modifié la géométrie de ces strates La phase initiale de la déformation correspond à une transposition progressive de la stratigraphie accompagnée de la formation de plis serrés à isoclinaux qui culminent dans des zones faiblement inclinés et fortement déformées. Cette déformation progressive semble avoir contrôlé la répartition de la minéralisation aurifère. Des plis surimprimés à plongement doux et de direction nord-est–sud-ouest ont modifié davantage la géométrie du corps minéralisé.

INTRODUCTION

The Meadowbank gold deposits are polydeformed, auriferous iron-formations within the Woodburn Lake group of the western Churchill Province (Fig. 1). The deposits are located about 70 km north of Baker Lake and are 100% owned by Cumberland Resources Ltd. who are currently conducting a prefeasibility study. Cumberland has identified a classified resource of about 2 000 000 ounces (Table 1), of which 962 400 are considered to be a proven and probable open-pit reserve (Cumberland Resource Ltd., Press Releases: March 29, 2000; April 27, 2000).

As one of the most advanced projects in the area, establishing the specific controls on mineralization at Meadowbank is an important initial step in evaluating the exploration potential of the northern Churchill Province. The correlative Prince Albert group, to the north of Meadowbank (Fig. 1), is a series of supracrustal belts with similar ages and lithologies to the Woodburn Lake group (Schau, 1982) which may host 'Meadowbank-like' deposits. The Canada–Nunavut Geoscience Office has recently initiated a project to map the Prince Albert group (Sandeman et al., 2001) — an understanding of the Meadowbank deposit will provide part of the geological framework in which to evaluate the exploration potential of these similar rocks.

REGIONAL GEOLOGY

The geology of northwest Hudson Bay consists of Archean and Proterozoic supracrustal sequences and plutonic rocks (Fig. 1). The Archean supracrustal sequences (e.g. Woodburn Lake and Prince Albert groups) are intruded by (ca. 2.60 Ga, Kenoran) orogenic granites, which are in turn unconformably overlain by pre-Hudsonian Proterozoic basins (e.g. Amer and Hurwitz groups). Post-Hudsonian basins (e.g. Baker Lake and Thelon basins) unconformably overlie both sequences, forming an overlap assemblage. The Woodburn Lake group is Archean, but has been overprinted by the Paleoproterozoic Hudsonian Orogeny (Henderson et al., 1991). The extent of Proterozoic reworking and the implications for gold mineralization in the district are uncertain.

The Woodburn Lake group has been mapped at 1:1 000 000 scale by Wright (1967), and 1:250 000 by Fraser (1988). More detailed work (1:100 000) was completed by Henderson and Henderson (1994), and the area has recently been the subject of a systematic 1:50 000 scale mapping project (Zaleski et al., 1997a, 1999a). Deposit-scale and regional metallogenic studies have been undertaken by Armitage et al. (1996), Kerswill (2000), and Kerswill et al. (1998, 2000).

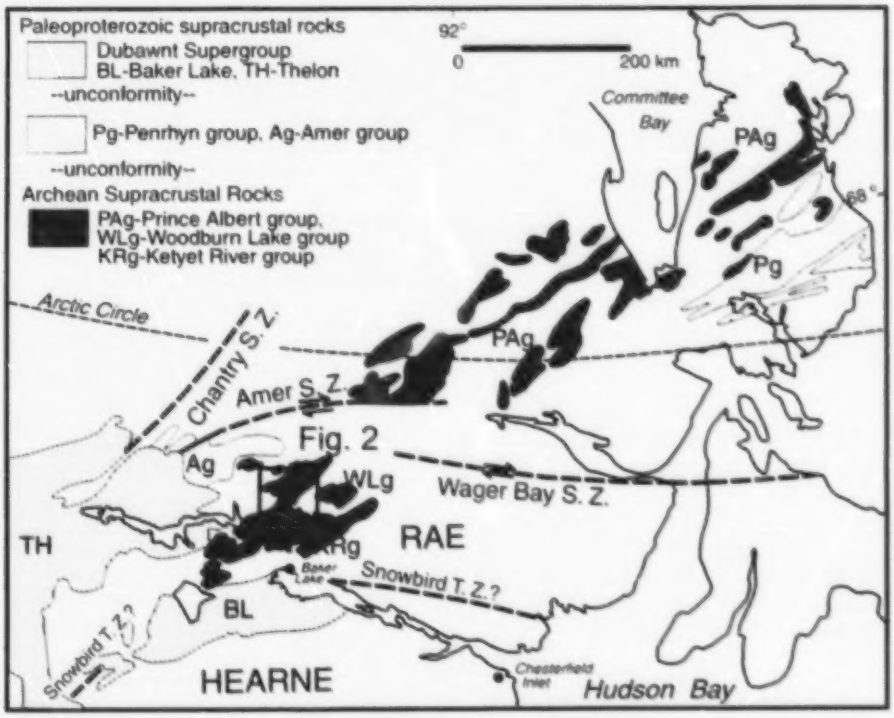

Figure 1. *Regional geological sketch map of the western Churchill Province, showing the distribution of Archean supracrustal rocks in the Woodburn Lake group (WLg), the Prince Albert group (PAg), and the Ketyet River group (KRg) relative to the Paleoproterozoic suites of the region (Zaleski et al., 1997b).*

Table 1. Cumberland Resource Ltd. press release March 29, 2000; April 27, 2000.

Total			
Class	**Tonnes**	**Grade (g/t)**	**Ounces**
Measured	1 191 000	6.58	252 100
Indicated	6 584 000	5.65	1 196 200
Inferred	3 467 000	5.60	623 800
Total	11 242 000	5.73	2 072 100
Third Portage			
Class	**Tonnes**	**Grade (g/t)**	**Ounces**
Measured	1 031 000	6.40	212 000
Indicated	4 914 000	5.31	839 700
Inferred	1 427 000	5.66	2 59 700
Total	7 372 000	5.53	1 311 400
Goose Island			
Class	**Tonnes**	**Grade (g/t)**	**Ounces**
Measured	75 000	10.63	25 700
Indicated	636 000	9.80	200 400
Inferred	456 000	9.50	139 400
Total	1 167 000	9.74	365 500
Bay Zone			
Class	**Tonnes**	**Grade (g/t)**	**Ounces**
Measured	51 000	5.38	8 800
Indicated	394 000	4.67	49 100
Inferred	239 000	4.64	35 500
Total	684 000	4.71	103 400
North Portage			
Class	**Tonnes**	**Grade (g/t)**	**Ounces**
Measured	34 000	5.10	5 600
Indicated	640 000	4.71	97 000
Inferred	1 345 000	4.38	189 200
Total	2 019 000	4.49	291 800
Open pit mining reserve			
	Tonnes	**Grade (g/t)**	**Ounces**
*P/P reserve	5 502 000	5.44	962 400

*Proven and probable mining reserve. All deposits except Goose Island are reported at a 2.5 g/t gold cutoff. Goose Island is reported at a 6 g/t gold cutoff. Bay Zone and Third Potage deposits assays were capped at 45 g/t gold; Goose Island assays were capped at 35 g/t gold; no assay capping was applied to North Portage. Resource and reserve classifications are in accordance with the Canadian Institute of Mining, Metallurgy and Petroleum guidelines.

The Woodburn Lake group (Fig. 2) includes quartzite and oligomictic conglomerate, ultramafic to mafic volcanic rocks, felsic to intermediate volcanic rocks and derived sedimentary rocks with interbedded iron-formation (Henderson et al., 1991; Zaleski et al., 1997b). Several phases of deformation have affected the stratigraphy, with four events recognized regionally (Pehrsson et al., 2000). The supracrustal sequences have been intruded by a series of felsic rocks, some of which preserve D_1 and D_2 foliations.

Woodburn Lake group felsic volcanic rocks have been dated at 2.74–2.71 Ga and 2.63 Ga (Zaleski et al., 2000; Davis and Zaleski, 1998), suggesting two volcanic sequences (Davis and Zaleski, 1998). Detrital zircons, from quartzite that structurally overlies the deposit, range from 3.0 to 2.81 Ga, with the majority of the grains at 2.96 Ga (Davis and Zaleski, 1998). The supracrustal rocks have been intruded by felsic rocks that have a D_1 fabric dated at 2620 Ma and a D_2 fabric dated at 2599 Ma (Davis and Zaleski, 1998; Pehrsson et al., 2000). Felsic intrusions east and west of the Meadowbank deposits give ages of 2612 ± 4 Ma (Figure 2; Roddick et al., 1992). The supracrustal rocks are also crosscut by undeformed, granitic, pegmatitic dykes that have an age of 1835 Ma (Roddick et al., 1992). Porphyroblastic biotite from the Third Portage area gave a K-Ar age of 1791 ± 32 Ma (Armitage et al., 1996).

GEOLOGY OF THE MEADOWBANK AREA

The Meadowbank area (Fig. 3) has been the focus of exploration activities since its discovery by Asamera Minerals Inc. in 1987 (Armitage et al., 1996). Most of the work in recent times (1995–1999) has focused on definition of the Third Portage, North Portage, Goose Island, and the Bay Zone deposits, collectively referred to as the Meadowbank deposits. Exploration has been focused on defining the geometry of the mineralized bodies via closely spaced diamond drilling and trenching. The following describes the rock types observed on the property and the sequence of structural events that have deformed them.

Felsic–intermediate volcanic rocks (IV)

The felsic to intermediate volcanic rock package is the dominant rock type recognized in the Meadowbank area. This unit may be subdivided into several subtypes:

1. Massive felsic flows to subvolcanic intrusive rocks (Fig. 3) are recognized to the east, in the structural footwall of the mineralized intervals at Third Portage. This unit is quartz- and plagioclase-feldspar-phyric with a groundmass of fine-grained quartz and biotite. Small quartz phenocrysts are abundant in this unit and are commonly blue.

2. Fine-bedded volcanic rocks (IV_b; Fig. 3) outcrop immediately east of the massive felsic flows and intrusive. Bed forms are commonly 1 to 5 cm and rarely show unambiguous internal sedimentary structures such as graded bedding. Beds are composed mainly of quartz and feldspar grains, which display a granular clastic texture, along with an assemblage of epidote-biotite-chlorite-muscovite. Locally, blue quartz phenocrysts occur, similar to those found in the massive units.

3. Medium-bedded volcanic rocks (IV_b; Fig. 3) are commonly interbedded with the iron-formation of the main mineralized intervals. These units are often relatively fine grained (sand sized) and form beds 20 cm to 3 m thick. Primary sedimentary features are rare. The beds are composed dominantly of quartz and feldspar grains with variable amounts of biotite-epidote-muscovite-chlorite. The beds are well sorted and homogenous in composition, but are not graded, suggesting mass flow emplacement from a homogenous source. Alternatively, these may represent

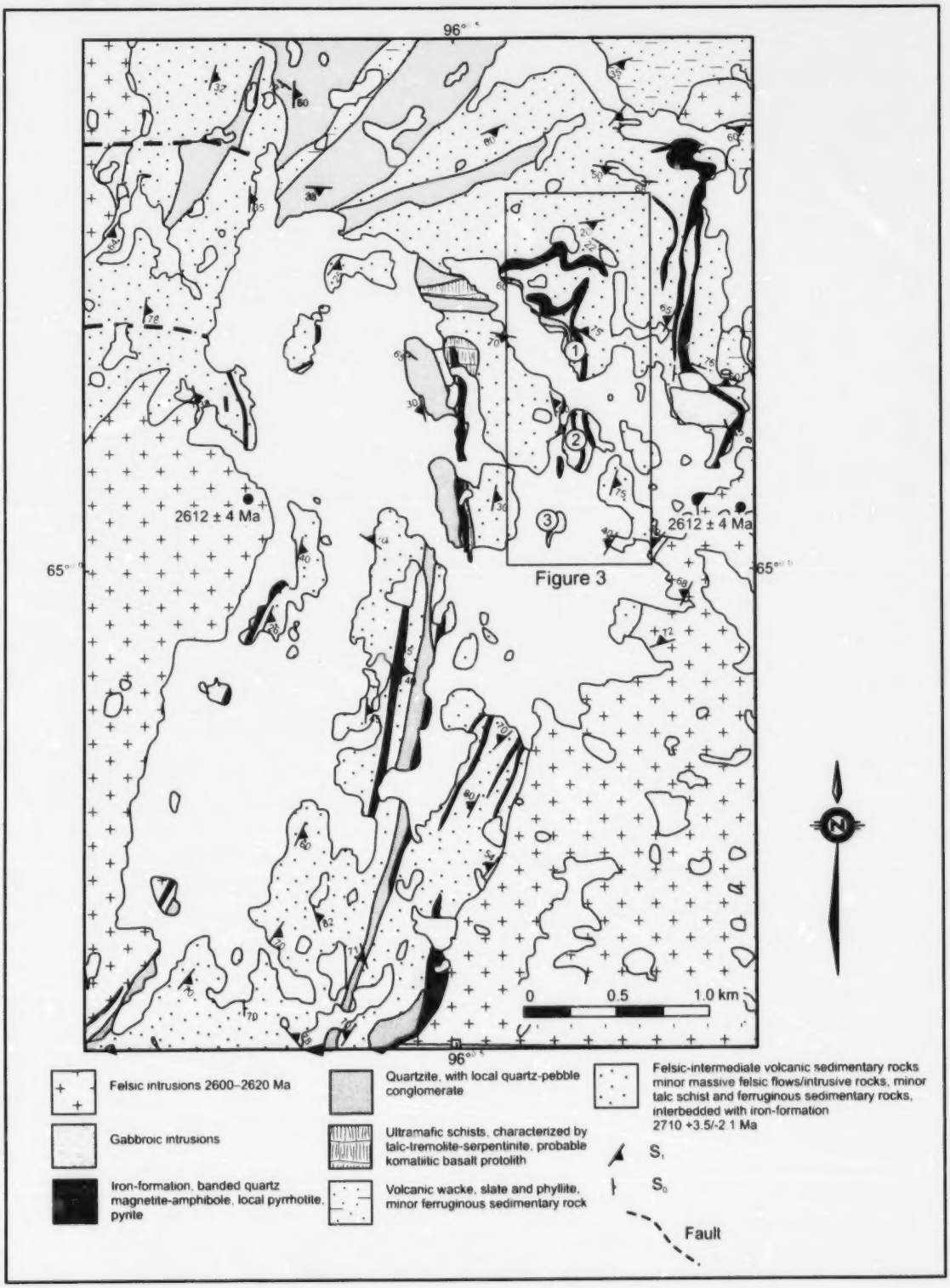

Figure 2. *Simplified geological map of the Woodburn Lake group in the Meadowbank area (Zaleski et al., 1997a, 1999a). Circled numbers: 1. North Portage deposit, 2. Third Portage deposit, 3. Goose Island deposit. The Bay Zone deposit is immediately southwest of Third Portage.*

agglomerated volcaniclastic beds. Locally, blue quartz phenocrysts occur similar to those found in the massive units.

4. Finely foliated volcanic rocks (IV_f; Figure 3) outcrop to the west of the Third Portage zone, within the structural hanging wall of the mineralization. Bed forms are rare, and the mineralogy is dominated by muscovite-chlorite-epidote with fewer quartz-feldspar grains. Locally, blue quartz phenocrysts are recognized similar to those in the massive and bedded units.

There exists a spectrum of rocks between the finely foliated, fine-, and medium-bedded volcanic rocks, depending on their grain size, mineralogy, and the development of bed forms. The dominant rock types are shown in Figure 3.

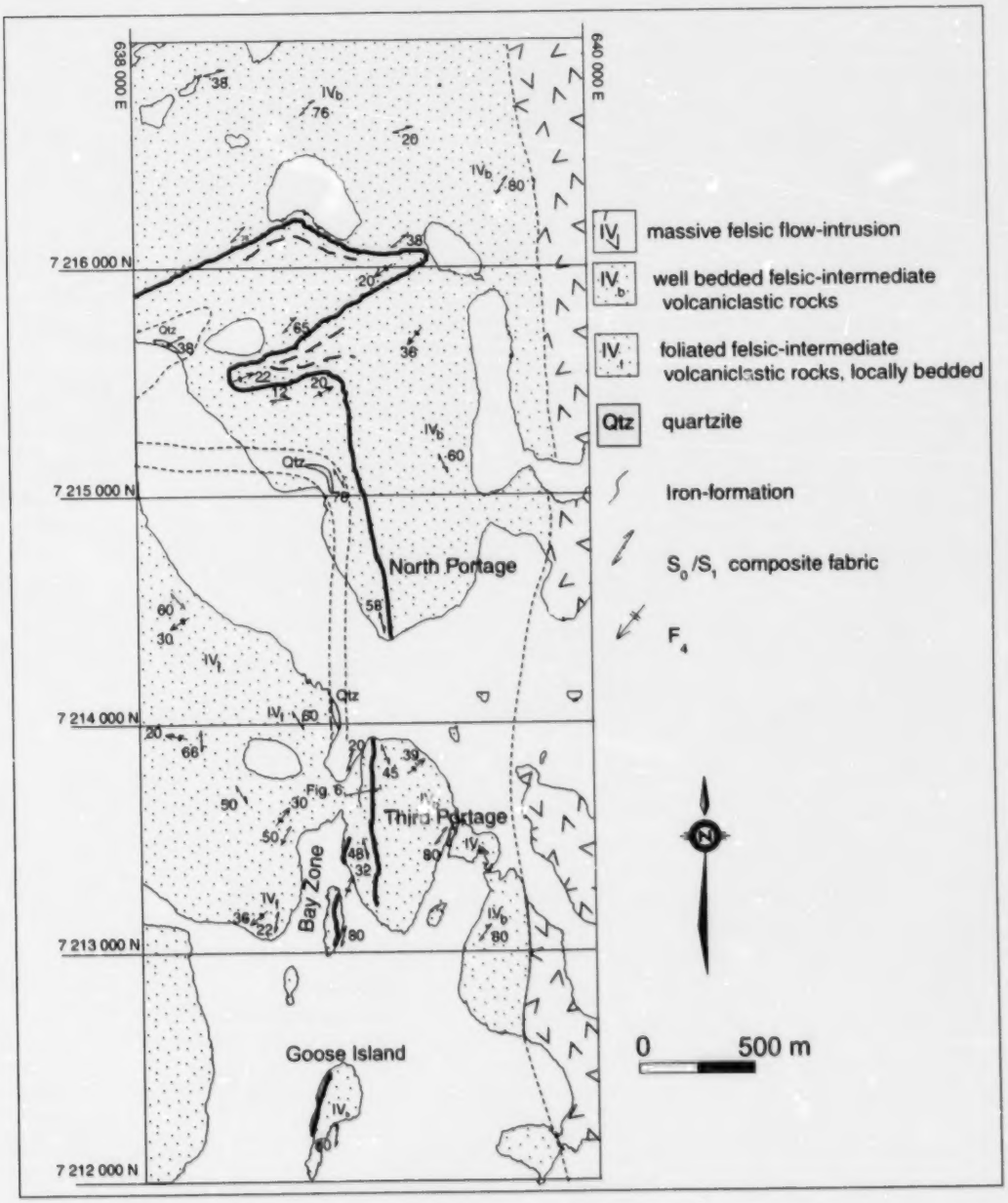

Figure 3. *Simplified geological map of the Meadowbank deposits showing the distribution of the rock types and tectonic fabrics. Cross-section in Figure 6 is shown in the Third Portage deposit.*

Iron-formation

Intervals of iron-formation comprising an assemblage of magnetite, quartz, and amphibole are interlayered with epiclastic sediments of the felsic-intermediate volcaniclastic rocks. Several iron-formation units have been identified, including the East BIF, Central BIF, and West BIF (Fig. 2). Of these only the Central BIF is auriferous. In areas of low strain, beds within the iron-formation are typically 0.2 to 10 cm thick and consist of alternating monomineralic layers of magnetite, quartz±amphibole. To the south, near Goose Island, garnet and biotite are developed in the iron-formation, suggesting higher metamorphic grades.

Quartzite

Massive to bedded and foliated quartzite units are exposed (Qtz; Fig. 3) in the western portion of the Meadowbank area in the structural hanging wall of the deposit stratigraphy. The bedded material has centimetre-scale bed forms defined by selvages of muscovite and epidote. The foliated quartzite comprises quartz, muscovite, and epidote, which define the foliations.

At the base of the quartzite, oligomictic conglomerate units have been intersected in drill cores. These units range from less than 1 m to more than 10 m in thickness. Local graded bedding provides younging directions. The conglomerate units are dominated by quartzite fragments, but also contain dark grey siliceous fragments as well as flattened fragments likely of mafic-ultramafic origin. Fuchsite-rich fragments are relatively common.

Ultramafic rocks

The ultramafic rocks comprise a massive sequence of talc-amphibolite-chlorite with textural variations in the size and colour of the amphiboles. This unit does not outcrop in the immediate Meadowbank area, but is commonly intersected in drill core. Only rarely are primary features such as spinifex textures preserved. Massively crystalline amphibole-rich rocks, with minor talc, are common near the footwall contact of the ultramafic package. Locally, within the ultramafic sequence, mafic volcanic intervals have been identified in the Goose Island area. These rocks have plagioclase±pyroxene phenocrysts in a finer grained chloritic groundmass.

Mafic tuff

Intervals of mafic tuff, interbedded with the iron-formation, are recognized locally in the felsic to intermediate volcanic package. These are narrow, generally less than 20 cm thick, and composed of chlorite and coarse biotite porphyroblasts.

Intrusive rocks

The supracrustal rocks at Meadowbank are bracketed to the east and west by large granitic intrusive bodies (Fig. 2). These intrusions locally preserve the dominant S_1 fabric described below. Locally, quartz- and feldspar-phyric dykes are intersected in drill core between the Third and North Portage deposits. These bodies are discontinuous and contain Cu-Au mineralization (described below). Narrow, undeformed lamprophyre dykes are also recognized in drill core.

Metamorphism

The metamorphic assemblages at Meadowbank are characterized by chlorite-epidote-muscovite-biotite-calcite in the volcanosedimentary strata: interpreted to reflect regional greenschist-facies metamorphic conditions. The iron-formation units are characterized by an assemblage of quartz-amphibole-magnetite±sulphides. To the south, at Goose Island, the iron-formation units are characterized by a quartz-amphibole-biotite-garnet mineral assemblage. This suggests a transition from greenschist at the Third Portage, to lower amphibolite metamorphic assemblages at Goose Island, with the garnet isograd transecting Third Portage and Goose Island deposits.

Structure

The volcanosedimentary sequence at the Meadowbank area is polydeformed, with four events recognized regionally (Pehrsson et al., 2000), two of which have significantly affected the geometry of the mineralized bodies. To clarify terminology we will adopt the deformation nomenclature of Pehrsson et al. (2000).

D_1–D_2

D_1 consists of a penetrative composite transposition foliation (S_0/S_1) and shallow-plunging, often rootless, isoclinal folds that are particularly well developed in the iron-formation. D_2 consists of a spaced to penetrative fabric (S_2) and tight to isoclinal, generally intrafolial, folds (F_2) which are shallowly north-south plunging and northeast-east verging in the Third Portage area and northwest-north verging in the North Portage area.

The transposed composite S_0/S_1 fabric is the principal fabric observed. The degree of S_1 development indicates that compositional layering preserved throughout the area should not be considered primary. Poles to S_0/S_1 (Fig. 4a, b) form a weak girdle, suggesting folding around a moderately plunging northeast-trending axis, consistent with F_4 described below. Coarse-grained amphibole rosettes overprint D_1-related fabrics.

The D_1–D_2 deformation is considered here as a progressive event with refolding or buckling of the transposed S_0/S_1 fabric, generating tight to isoclinal folds (F_2) which exhibit moderately west-dipping enveloping surfaces in the Third Portage area. The culmination of D_1–D_2 deformation involved the development of penetrative S_2 fabrics and locally low-angle, high-strain zones axial planar to F_2 (Fig. 4c, d). These high-strain zones often exploit lithological contacts between ultramafic and volcanosedimentary rocks where rheologic contrasts have focused strain gradients into

the volcanosedimentary rocks. These strong S_2 fabrics crenulate amphiboles, suggesting either several generations of metamorphic amphiboles or that D_2 occurred after peak metamorphism.

D_4

Folded D_1–D_2 fabrics are typically open to closed, angular to subrounded, and generally 'S' shaped in the Meadowbank area. Axial surfaces are upright, northeast-southwest trending, and doubly plunging (Fig. 5a, b, c). The geometry of F_4 is locally controlled by the orientation of the earlier fabrics (Pehrsson et al., 2000). Fold-interference patterns are common, resulting from the superposition of upright F_4 folds on tight and inclined F_2 folds. A spaced to penetrative axial-planar cleavage (S_4) is locally well developed and overprints earlier fabrics as well as crenulating amphibole rosettes. D_4 fabrics fold and deform mineralization.

There are weakly developed, generally open warps of earlier fabrics in the Meadowbank area which may represent an additional phase of deformation, possibly D_3 of Pehrsson et al. (2000). Locally there is a weak northwest-north axial-planar spaced cleavage which crenulates earlier fabrics and also deforms amphibole rosettes. The effect of this event on the overall geometry of the mineralized bodies is minor.

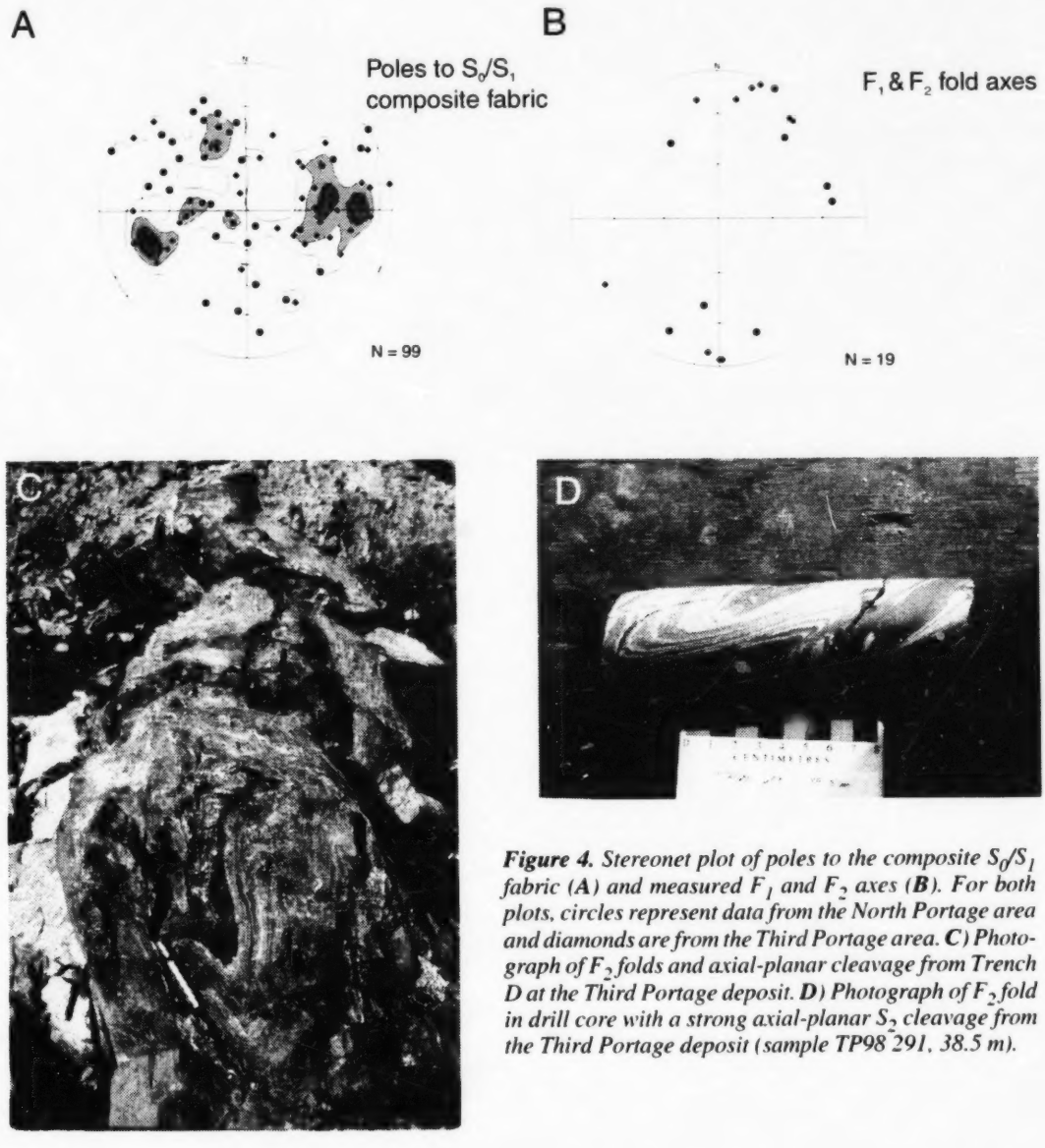

Figure 4. *Stereonet plot of poles to the composite S_0/S_1 fabric (**A**) and measured F_1 and F_2 axes (**B**). For both plots, circles represent data from the North Portage area and diamonds are from the Third Portage area. **C**) Photograph of F_2 folds and axial-planar cleavage from Trench D at the Third Portage deposit. **D**) Photograph of F_2 fold in drill core with a strong axial-planar S_2 cleavage from the Third Portage deposit (sample TP98 291, 38.5 m).*

Gold mineralization

There are four discrete areas where gold occurs in sufficient concentrations to have justified a resource figure in the Meadowbank area. These include, from north to south, the North Portage, Third Portage, Bay Zone, and Goose Island deposits (Fig. 3). Of the four areas, the Third Portage deposit is volumetrically the largest and closest to the surface. The mineralization at Meadowbank should be best considered as several auriferous iron-formation units within a broad stratigraphic package. The zones show many similarities and are located within the same broad structural regime.

The distribution of gold in the Third Portage deposit is well defined by closely spaced drilling (~25 m) and surface trenching (Fig. 6), and is similar in style and geological setting to the adjacent North Portage, Bay Zone, and Goose Island deposits. Mineralization at the Third Portage deposit is best developed at the lithological contact between an ultramafic body and the volcanosedimentary package. The ultramafic body may represent the core to an east-verging antiform, or alternatively may be a boudin within the transposed/flattened stratigraphy (Fig. 6). Mineralization is almost entirely restricted to the structural footwall or the hinge area of the ultramafic body; occurring only sporadically and weakly in the structural hanging wall of the ultramafic unit. The hanging wall is low-strain with planar lithological contacts and S_0/S_1 fabrics, whereas the footwall is generally higher strain with contorted F_2 folds and strong S_2 fabrics.

Gold is contained within sulphide-bearing iron-formation (Armitage et al., 1996; Kerswill et al., 1998), characterized by disseminated to semimassive pyrrhotite-pyrite which preferentially replaces magnetite (Armitage et al., 1996). Mineralization is also developed in the felsic-intermediate volcanic package as disseminated pyrrhotite and pyrite along with narrow grey quartz veins also containing pyrrhotite and pyrite.

Sulphides show a variety of relationships with deformation fabrics. Pyrrhotite, pyrite, and sulphide-bearing quartz veins can be aligned along S_0/S_1 fabrics as well as within S_2 foliations overprinting S_0/S_1 fabrics (Kerswill et al., 2000; Pehrsson et al., 2000). Spatially, at the Third Portage deposit,

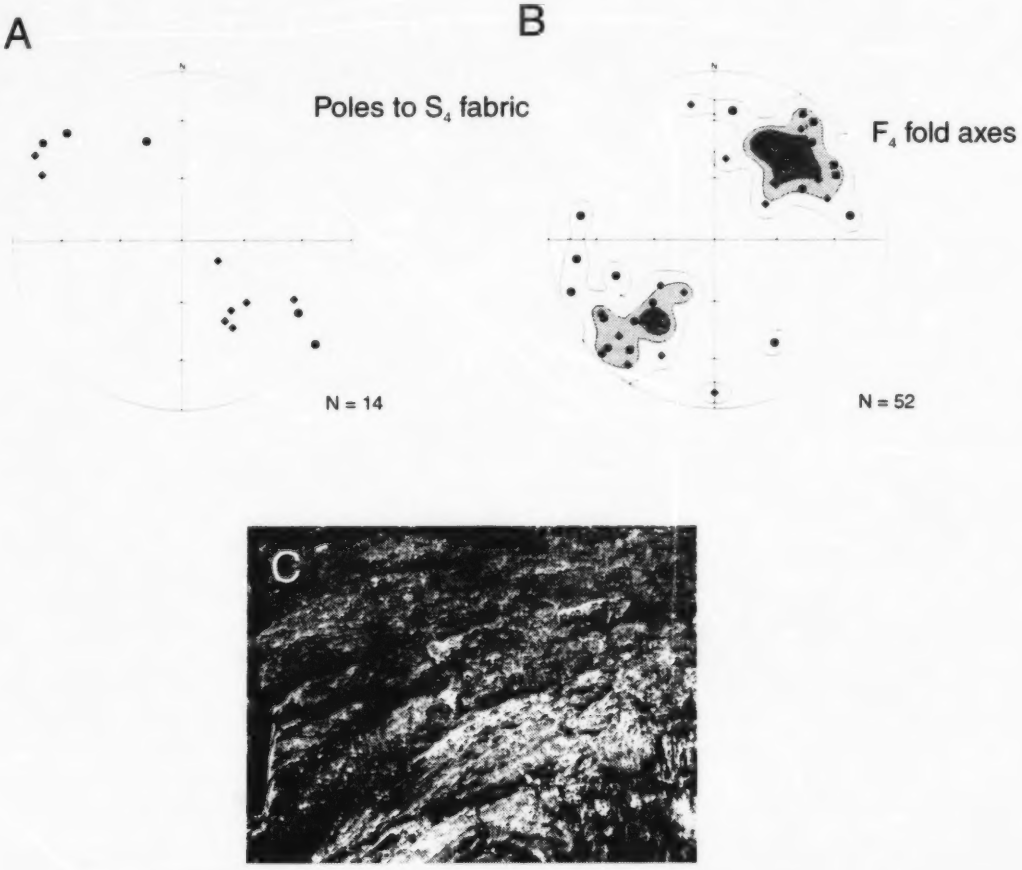

Figure 5. *Stereonet plot of poles to S_4 fabric (**A**) and measured F_4 axes (**B**). For both plots, circles represent data from the North Portage deposit and diamonds from the Third Portage deposit. **C**) Photograph of F_4 folds from the North Portage area.*

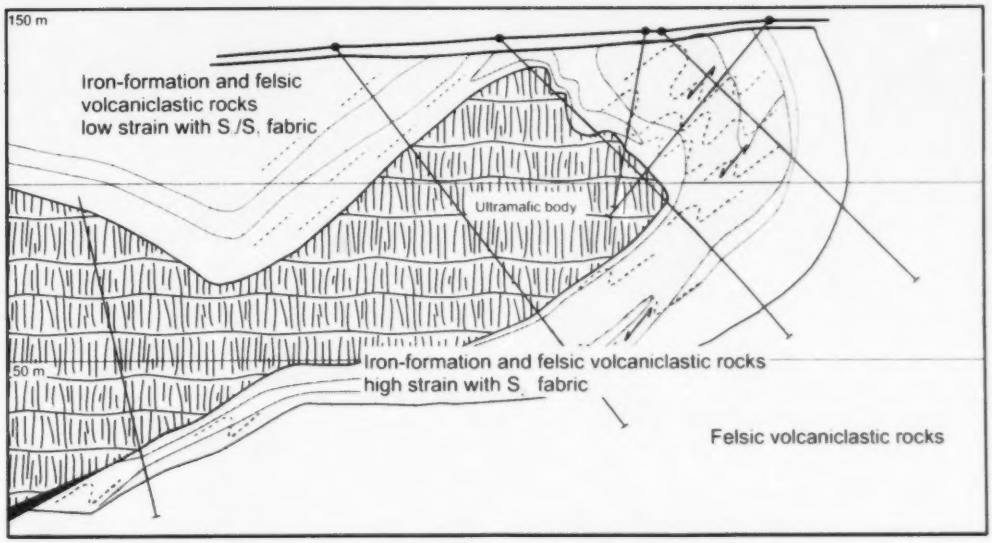

Figure 6. *Simplified cross-section through the Third Portage deposit at section 1+80N. This shows the distribution of gold and deformation fabrics around the ultramafic body. The shaded area represents an interpreted mineralized envelope; any material within the shaded areas will average greater than 1.0 g/t gold.*

the bulk of the mineralization is concentrated at the structural footwall or hinge area of ultramafic units within, and adjacent to, high-strain zones defined by penetrative S_2 fabrics. This suggests either different generations of sulphides or that the sulphides are related to the progressive D_1–D_2 deformation event and concentrated in areas of higher strain.

The degree of transposition of the host stratigraphy makes it difficult to trace individual units within the felsic volcaniclastic and iron-formation package. Even in the Third Portage area, where trenching and closely spaced diamond drilling provides exceptional data density, the surface trace of the individual units is uncertain. The gold mineralization, however, is continuous along strike and down dip. Mineralized envelopes of more than 1.0 g/t Au show good continuity and can be traced for hundreds of metres. It is this feature of the mineralization that has enabled Cumberland to produce a proven-probable mining reserve. Mineralization occurs in iron-formation and volcaniclastic rocks and is more continuous than any individual stratigraphic interval.

Based on whole-rock and mineral chemistry, Armitage et al. (1996) have shown that auriferous iron-formation units are characterized by a mineral assemblage of cummingtonite and biotite with pyrrhotite-pyrite-magnetite and quartz. Barren, but sulphidic, iron-formation units are characterized by an assemblage of grunerite±hornblende+stilpnomelane with pyrrhotite, pyrite, quartz, and magnetite. Whereas barren, non-sulphide-bearing, iron-formation units are characterized by quartz and magnetite. Based on these mineral assemblages and their relationship to gold mineralization, Armitage et al. (1996) have suggested that mineralization is related to metasomatic fluids that have altered the iron-formation with the introduction of Mg-K-Ca-S-As-Cu and Au during D_1–D_2 deformation.

Although speculative, it is possible that metasomatic fluids, introduced into dilational sites during D_1–D_2 deformation, altered the iron-formation and locally the volcaniclastic rocks. The mechanical contrast between the ultramafic and volcaniclastic rocks partitioned strain into the volcaniclastic rocks and iron-formation, which preferentially localized dilational settings. This allowed fluid influx and the resulting alteration assemblages, described by Armitage et al. (1996), to be concentrated in the higher strain corridor adjacent to the ultramafic rocks. The progressive nature of D_1–D_2 formed the various relationships of sulphide minerals and deformation fabrics.

Other styles

Quartz–base-metal sulphide veins are also recognized. These veins are late (occurring after D_1–D_2) coarse grained and relatively narrow, locally containing base-metal sulphides and silver (Kerswill et al., 1998). These veins crosscut S_1 fabrics and may be related to a later, possibly intrusive, event.

Coarse-grained quartz-feldspar-porphyritic intrusions have been recognized in several areas between Third Portage and North Portage. Pyrrhotite and chalcopyrite occur throughout the unit as disseminations and veinlets of quartz and sulphides with chlorite selvages. In addition to containing several per cent chalcopyrite, gold grades are anomalous; locally 1 m intervals may contain in excess of 1.0 g/t gold, but typically contain less than 0.5 g/t gold. This unit is massive and

unfoliated, but contains little in the way of micaceous minerals to manifest a foliation. The geometry of the intrusive bodies is parallel to S_1, suggesting that they may have been rotated into that orientation or may have exploited S_1 fabrics during intrusion.

TIMING OF MINERALIZATION

Pehrsson et al. (2000) have suggested that the minimum age of D_1 is 2.62 Ga, which is the age of the oldest granite with D_1 fabrics. The maximum age of D_2 is 2599 Ma, which is the age of the youngest granite with D_2 fabric. The younger boundary for D_2 deformation is 1835 Ma, the age of the youngest undeformed crosscutting pegmatite dyke swarm. Davis and Zaleski (1998) and Pehrsson et al (2000) have suggested that given the similarity in attitude and vergence of D_2 structures of the Woodburn Lake group and the Amer fold-thrust belt, it is possible that D_2 is Paleoproterozoic.

As outlined above, the mineralization is interpreted here to be related to the progressive D_1–D_2 event. Based on the fabrics developed in granites, D_1–D_2 occurred between 2599 and 1835 Ma, and based on the crenulation of amphiboles, occurred after peak metamorphism, although different metamorphic events are likely. Further constrains on the timing may be possible with detailed geochronology on the deposit.

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